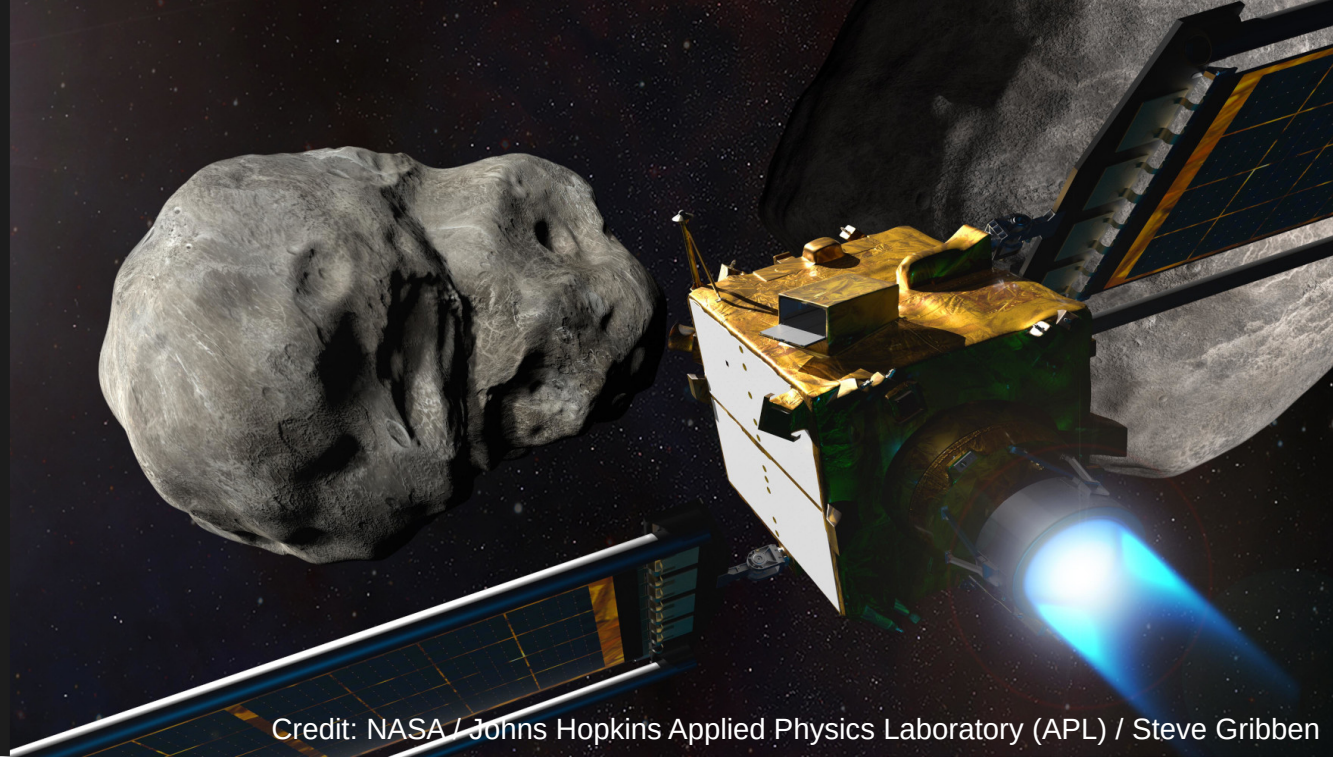


# Geospatial in space




Credit: NASA / Johns Hopkins Applied Physics Laboratory (APL) / Steve Gribben

Martin Desruisseaux (Geomatys)  
Jérôme Saint-Louis (ECERE)

# The Open Geospatial Consortium (OGC)

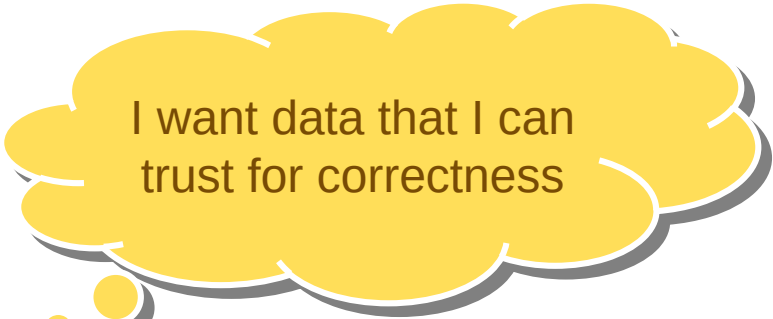
- Not-for-profit organization founded in 1994
- 500 members, big and small
  - Software industry (*Google, Apple, Oracle, ESRI*, small companies...)
  - Manufacturers (*Hitachi, Mitsubishi, Huawei, ...*)
  - Space agencies and aerospace (*NASA, ESA, Airbus, ...*)
  - Universities (*Harvard, United Nations University, ...*)
  - National mapping agencies, government, not-for-profit organizations, ...
- Develop international standards
  - Sometime jointly with *International Organization for Standardization (ISO)*
  - Sometime jointly with *World Wide Web Consortium (W3C)*
- **A community where developers and domain experts can join**

# Complementary focus



I want to access big data and be fast

Developer



I want data that I can trust for correctness

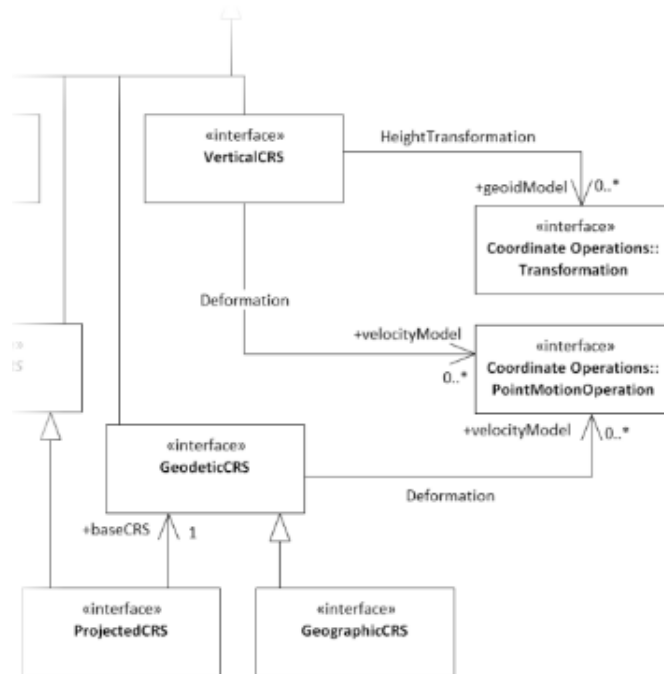
Domain expert

*“For every complex problem, there is a solution which is simple, neat, and wrong.”*

— derived from H. L. Mencken (1880-1956)

# Conceptual models

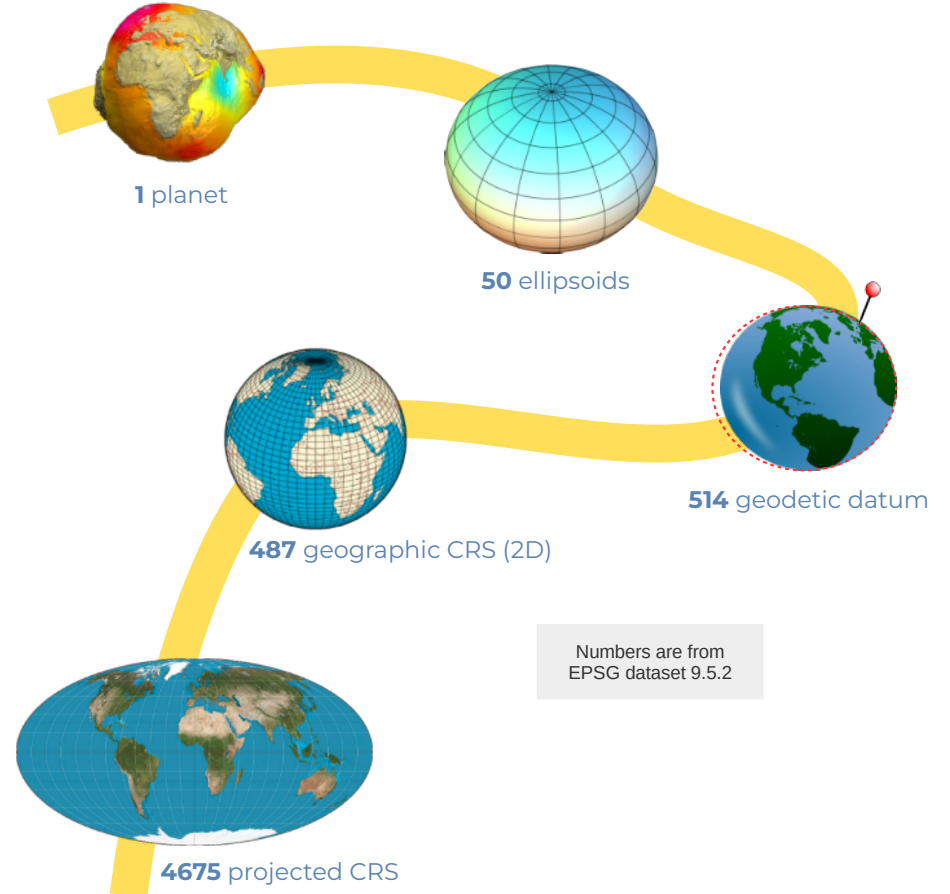
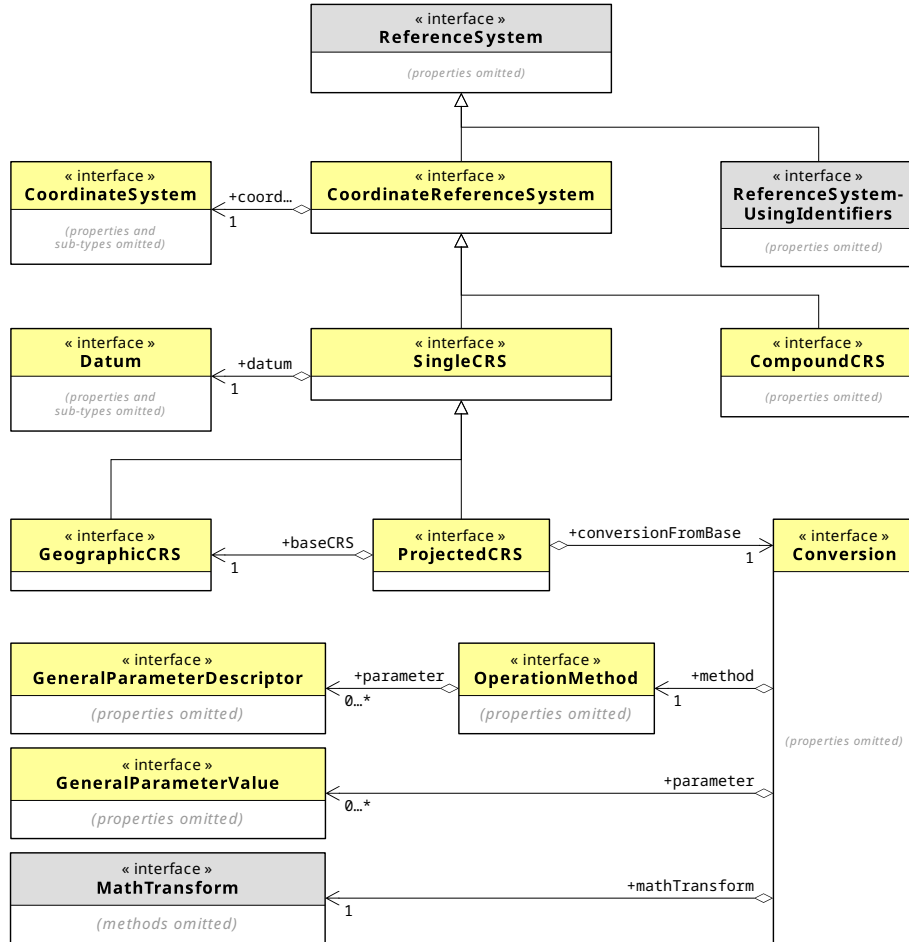
- Behind Web Services, there is abstract specifications
- Defined by Unified Modelling Language (UML)



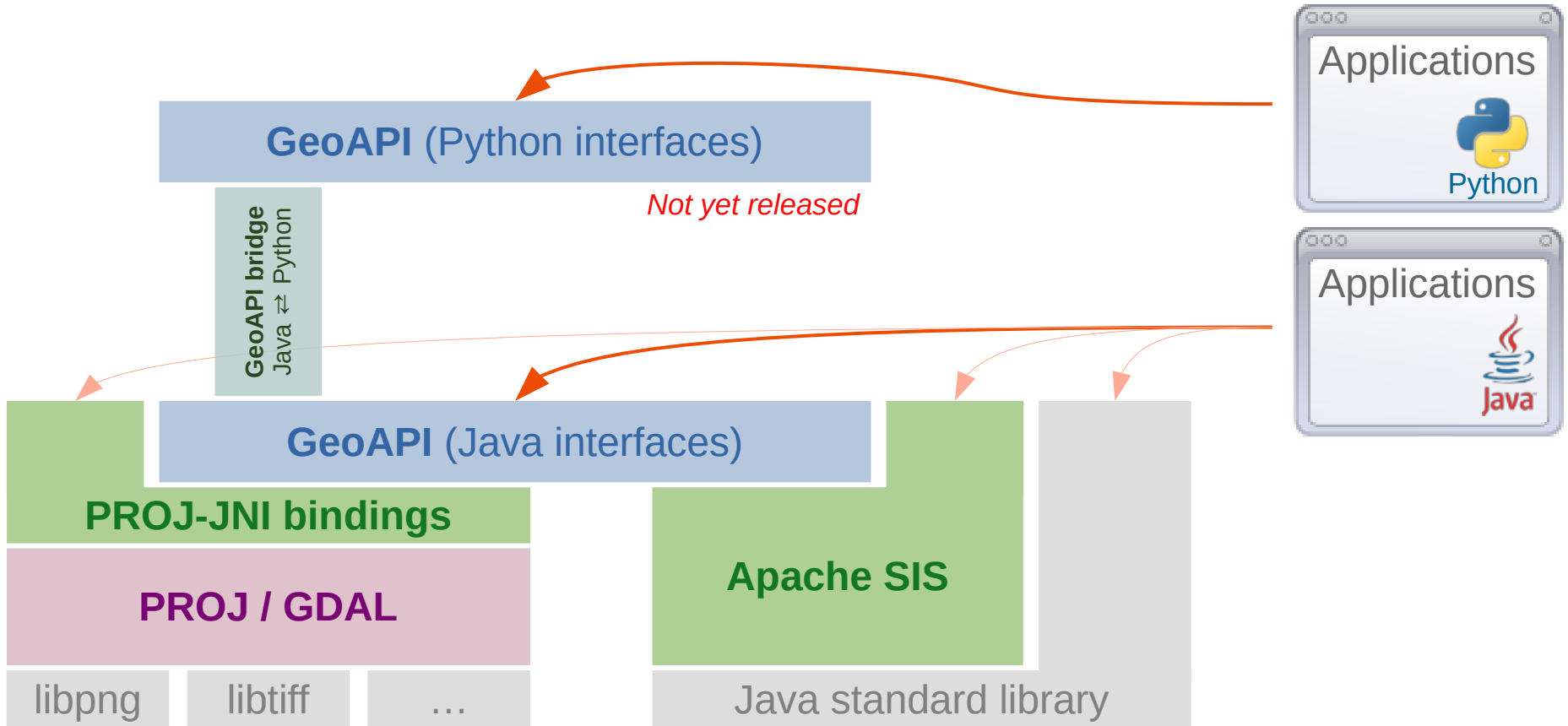
- ISO 19115 — Metadata
- ISO 19157 — Data quality
- ISO 19111 — Referencing
- ISO 19112 — Ref. by identifier
- ISO 19109 — Features
- ISO 19123 — Coverages
- ISO 19143 — Filtering

XML or WKT representations of above are defined in separated OGC/ISO standards.

# ISO 19111 — Referencing by coordinates



# GeoAPI interfaces (org.opengis® packages)



# Apache Spatial Information System (SIS)

- Java library for geospatial applications
- Strong focus on OGC/ISO standards
  - Metadata (ISO 19109)
  - Referencing services (ISO 19111)
  - Grid coverages
  - GeoAPI 3.0.2





# Usage examples (1/3)

- **Apache SIS**

```
import org.apache.sis.referencing.CRS;  
  
CRSAuthorityFactory dataset = CRS.getAuthorityFactory("EPSG");  
ProjectedCRS myDataCRS = dataset.createProjectedCRS("3395");
```

- **PROJ-JNI**

```
import org.osgeo.proj.Proj;  
  
CRSAuthorityFactory dataset = Proj.getAuthorityFactory("EPSG");  
ProjectedCRS myDataCRS = dataset.createProjectedCRS("3395");
```

 GeoAPI  
 Implementation

# Usage examples (2/3)

- **By authority code**

```
CoordinateReferenceSystem myDataCRS = CRS.forCode("EPSG:26747");
```

```
WARNING: Code "EPSG:26747" is deprecated and superseded by 26799.  
Reason is: Error in dependent projection record.
```

Apache SIS warns user if there is known issue with requested CRS

- **By Well Known Text (WKT)**

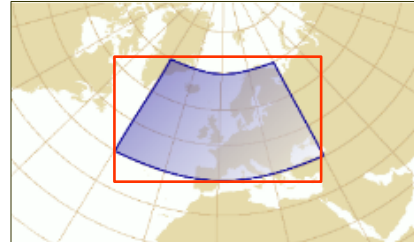
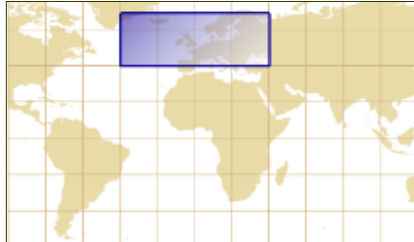
```
CoordinateReferenceSystem myDataCRS = CRS.fromWKT("PROJCRS[...]");
```

- **By Geographic Markup Language (GML)**

```
CoordinateReferenceSystem myDataCRS = CRS.fromXML("<gml:ProjectedCRS>...");
```

# Usage examples (3/3)

```
import org.opengis.referencing.operation.CoordinateOperation;  
  
// Class declaration omitted for brevity  
  
CoordinateReferenceSystem sourceCRS = // any method shown in other slides  
CoordinateReferenceSystem targetCRS = // any method shown in other slides  
CoordinateOperation op = CRS.findOperation(sourceCRS, targetCRS, region);  
  
// Verify domain of validity and accuracy  
System.out.println("Valid in " + CRS.getGeographicBoundingBox(op));  
System.out.println("Accuracy " + CRS.getLinearAccuracy(op) + " m");  
  
Envelope transformed = Envelopes.transform(op, envelope);
```

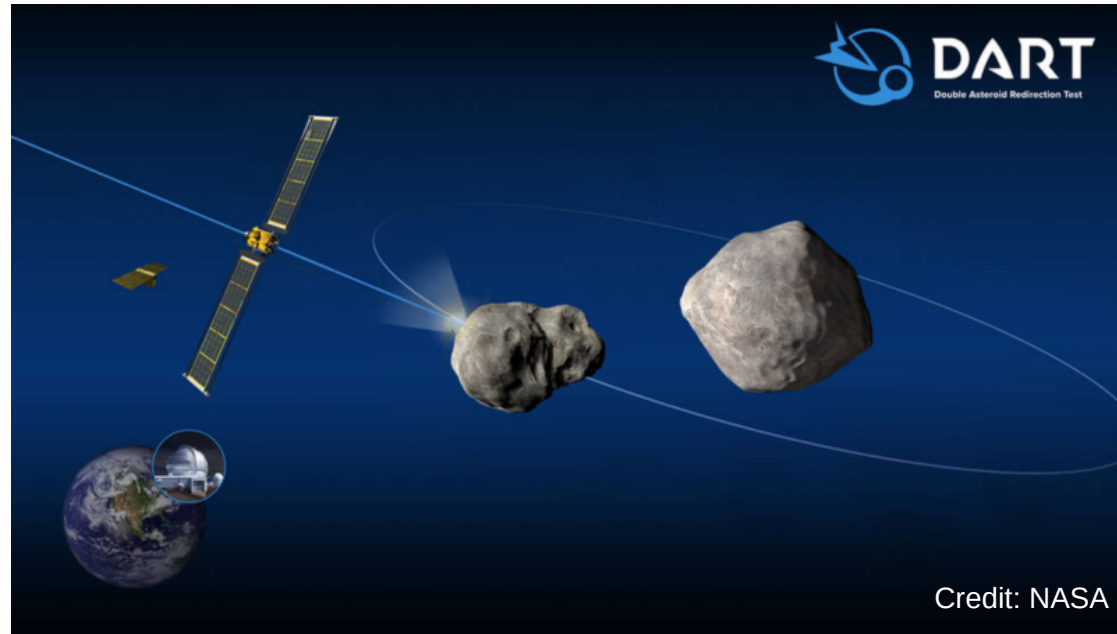


# OGC Testbed-18 & 19

Test applicability of existing OGC/ISO Standards for describing objects in orbit of any celestial body or in free flight in our solar system.

- Started in 2022
- Published as OGC Engineering Reports
- Propose extensions to ISO 19111 abstract model and GML encoding
- Propose IAU as a new authority for CRS definitions  
Some definitions available at <http://voparis-vespa-crs.obspm.fr:8080/web/mars.html>

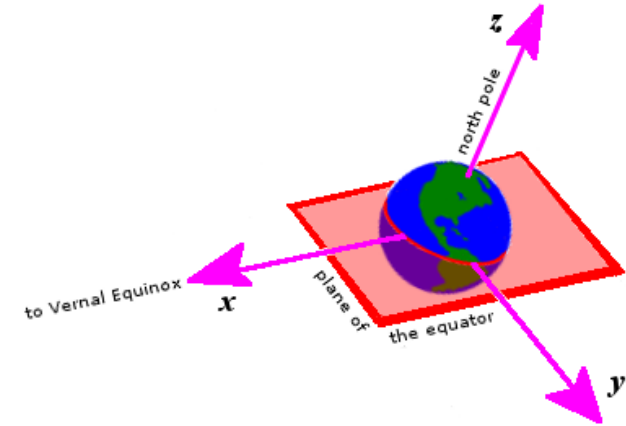
# Double Asteroid Redirection Test (DART)



- Many CRS: Sun, Earth, spacecraft, asteroid, its moon...
- Measured the changes of Dimorphos orbit around Didymos

# Barycentric Celestial Reference System

- Origin at the Solar System's center of mass
- Reference plane is the celestial equator
  - based on International Celestial Reference Frame (ICRS), defined by measuring quasars positions
  - fixed relative to far away extragalactic objects,
- Primary direction: March (Vernal) equinox
- 3D Cartesian form:  $x, y, z$  (units examples: au, km)
- Can also be described using spherical coordinates
  - declination ( $\delta$ , lat) and right ascension ( $\alpha$ , lon), range
- Minimizes effects of General Relativity for observations within Solar System

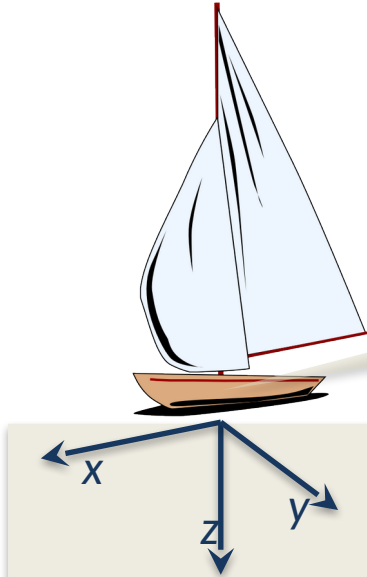


ICRF axes  
(geocentric here)  
source: [Wikipedia](#)

# Barycentric Coordinate Time (TCB)

- Time coordinate complementing BCRS
- Proper time for clock at rest moving in coordinate frame moving with Solar System center of mass
- Not influenced by gravity of solar system objects (e.g., Sun)
- Replacement for older Barycentric Dynamical Time (TDB)

# Coordinate Reference System for a vehicle



## Well-Known Text (WKT) 2

```
ENGCRS["A ship-centred CRS",  
  EDATUM["Ship reference point",  
    ANCHOR["Centre of buoyancy"]],  
  CS[Cartesian, 3],  
  AXIS["(x)", forward],  
  AXIS["(y)", starboard],  
  AXIS["(z)", down],  
  LENGTHUNIT["metre", 1]]
```

- Trajectory is stored separately
  - As a coordinate transformation
  - As a moving feature

# Coordinate Reference System for a planet

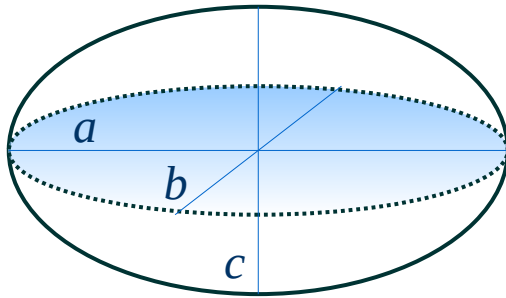


## Well-Known Text (WKT) 2

```
GEODCRS["WGS 84",  
  DATUM["World Geodetic System 1984",  
    CELESTIALBODY["Earth"],  
    ELLIPSOID["WGS 84", 6378137, 298.257223563, LENGTHUNIT["metre", 1]],  
  CS[ellipsoidal, 3],  
  AXIS["Latitude (P)", north, ANGLEUNIT["degree", 0.0174532925199433]],  
  AXIS["Longitude (L)", east, ANGLEUNIT["degree", 0.0174532925199433]],  
  AXIS["Ellipsoidal height (h)", up, LENGTHUNIT["metre", 1]],  
  ID["EPSG", 4979]]
```

- “Celestial body” is a proposed extension to ISO 19111
- Avoid datum shift non-sense if celestial body is not the same

# Triaxial ellipsoid



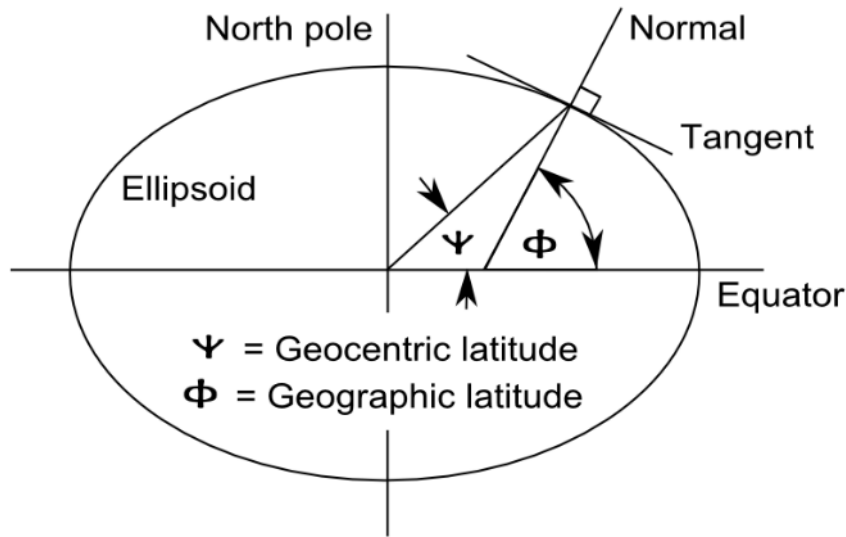
## Well-Known Text (WKT) 2

```
GEODETICCRS["Io",  
  DATUM["Io 2009",  
    TRIAXIAL["Io 2009 IAU IAG", 1829400, 1819400, 1815700]],  
  CS[ellipsoidal, 2],  
  AXIS["Latitude (Lat)", north],  
  AXIS["Longitude (Lon)", east],  
  UNIT["degree", 0.017453292519943295]
```

- Already in latest ISO 19111 / ISO 19162 standards

# Geodetic versus geocentric latitude

- Geographic systems use geodetic latitudes
- Planetary systems use both



## Geodetic latitude

```
GEODETIICRS["Mars",  
  DATUM["Mars",  
    ELLIPSOID["Mars reference", TBD]],  
  CS[ellipsoidal, 2],  
  AXIS["Geodetic latitude (Lat)", north],  
  AXIS["Geodetic longitude (Lon)", east],  
  UNIT["degree", 0.017453292519943295]
```

## Geocentric latitude

```
GEODETIICRS["Mars",  
  DATUM["Mars",  
    ELLIPSOID["Mars reference", TBD]],  
  CS[spherical, 3],  
  AXIS["Geocentric latitude (Lat)", north, UNIT[...]],  
  AXIS["Geocentric longitude (Lon)", east, UNIT[...]],  
  AXIS["Radial distance (R)", up, UNIT["metre", 1]]]
```

# High ellipsoid flattening

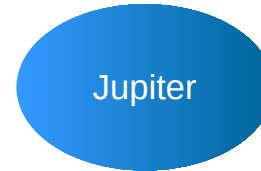
- Possible approximations of **elliptic integrals** for some map projections formulas:
  - 1) Series expansion: faster, but the number of terms is designed for Earth.
  - 2) Iterative calculation: adaptive but relatively slow.
- Apache SIS uses an hybrid approach for some projections.

$$\chi + C_1 \sin(2\chi) + C_2 \sin(4\chi) + C_3 \sin(6\chi) + C_4 \sin(8\chi) + C_5 \sin(10\chi) + C_6 \sin(12\chi) + \dots$$



Earth

Enough terms for a planet flattened like Earth.  
Map projection formulas typically stop here.

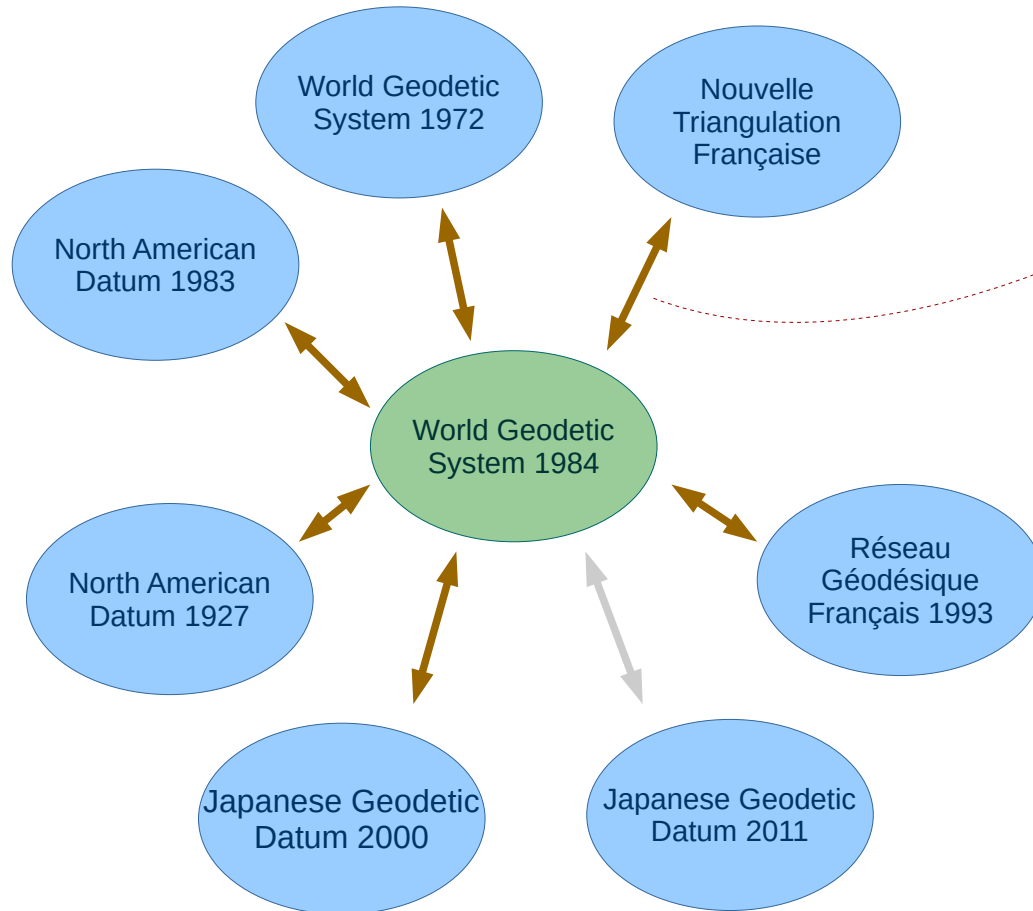


Jupiter

More terms needed for  
more flattened planets.



# Coordinate transformation — Early-binding

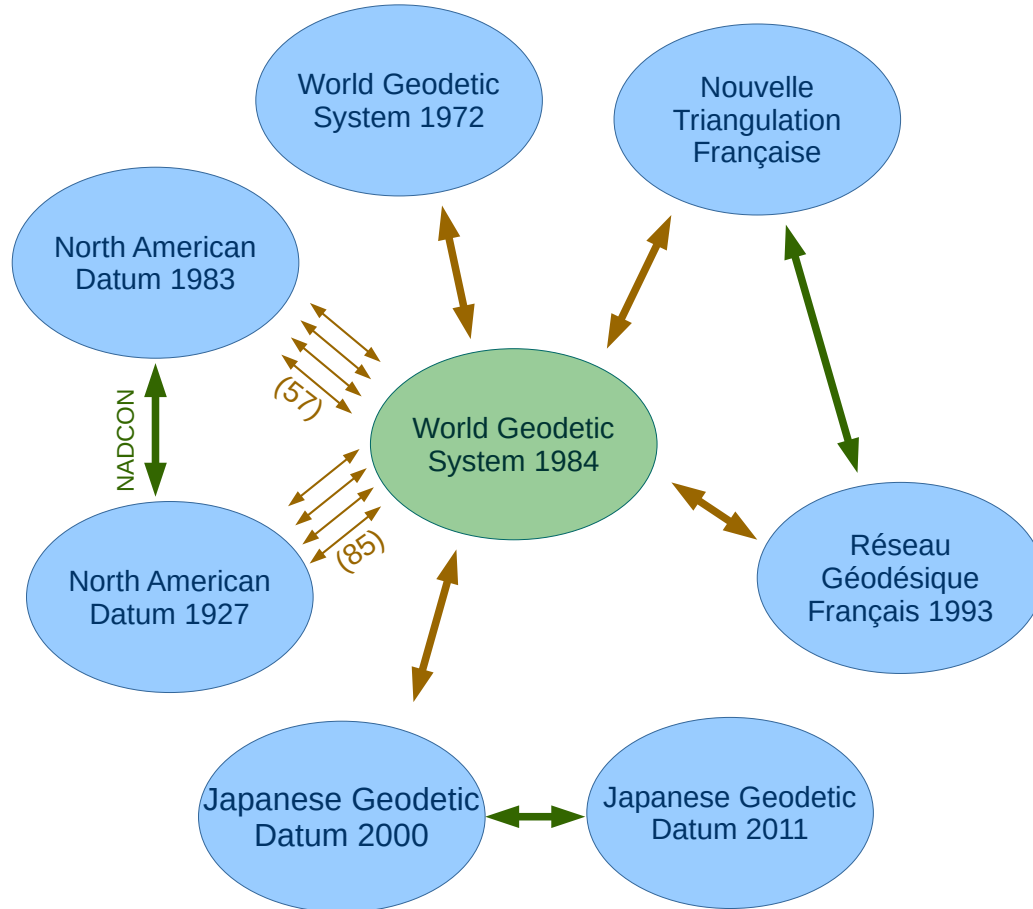


Well Known Text (WKT) format version 1:

```
GEOGCS["NTF",  
  DATUM["Nouvelle Triangulation Française",  
    SPHEROID["Clarke 1880 (IGN)", 6378249.2, 293.466...],  
    TOWGS84[-168, -60, 320]],  
  PRIMEM["Greenwich", 0],  
  UNIT["degree", 0.01745...],  
  AXIS["Latitude", NORTH],  
  AXIS["Longitude", EAST],  
  AUTHORITY["EPSG", "4275"]]
```

- Requires error-free functions
- Did not worked well on Earth
- Even more questionable in the context of Einstein's relativity

# Coordinate transformation — Late-binding



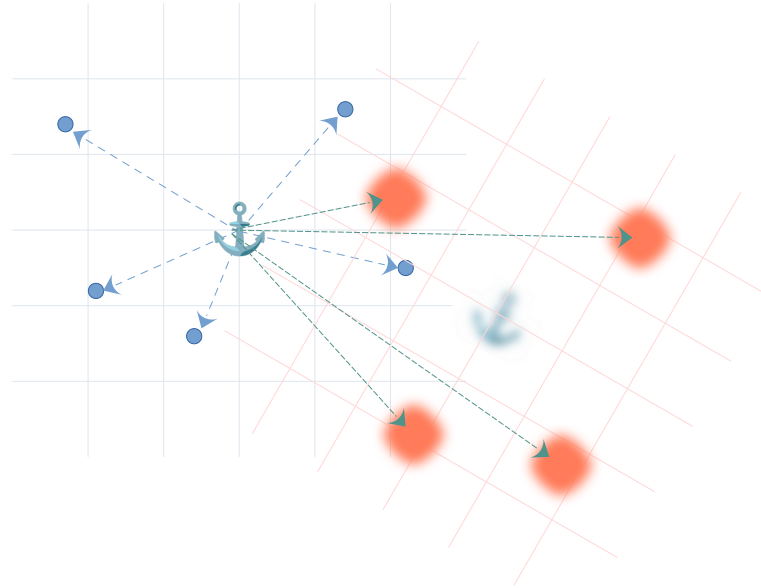
Well Known Text (WKT) format version 2:

```
GEODCRS["NTF",  
  DATUM["Nouvelle Triangulation Française",  
    ELLIPSOID["Clarke 1880 (IGN)", 6378249.2, 293.466...]],  
  PRIMEM["Greenwich", 0],  
  CS[ellipsoidal, 2],  
  AXIS["Latitude", north],  
  AXIS["Longitude", east],  
  UNIT["degree", 0.01745...],  
  ID["EPSG", 4275]]
```

**TOWGS84 is removed in WKT version 2**

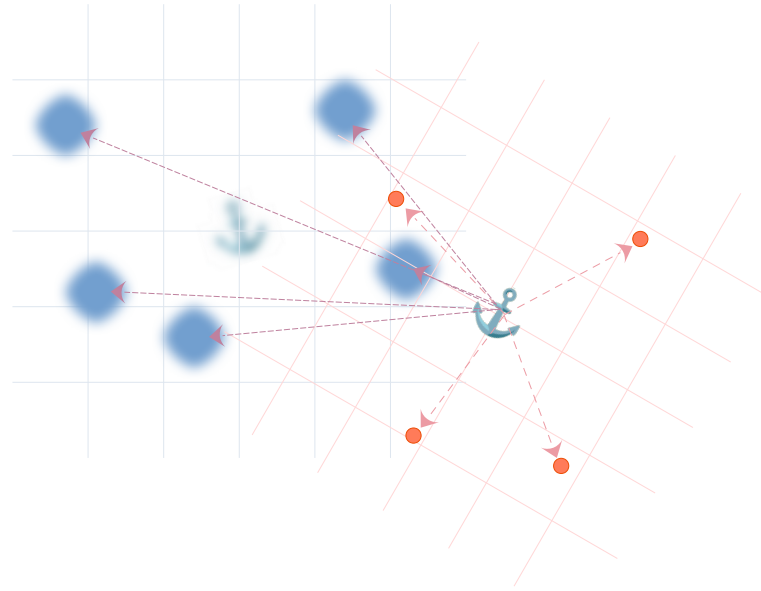
# Accuracy depends on choice of Reference Frame

Accurate in **blue** frame, stochastic errors in **red** frame

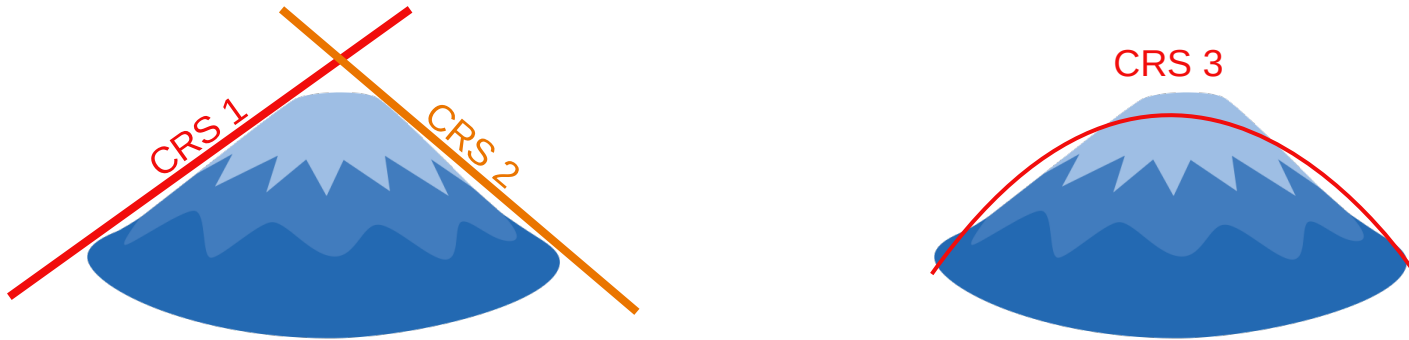


# Accuracy depends on choice of Reference Frame

Accurate in **red** frame, stochastic errors in **blue** frame



# Trade-off between extent and complexity



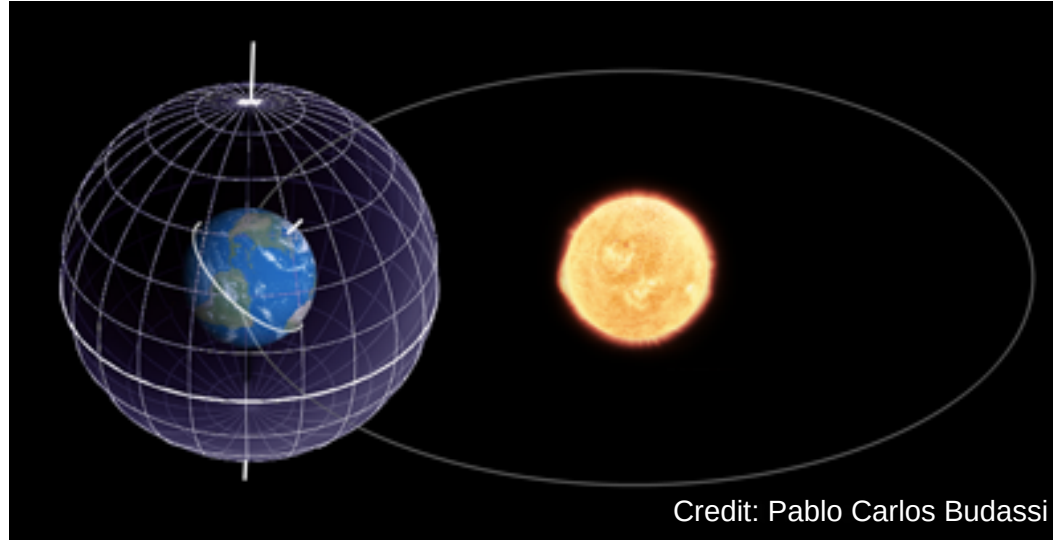
- One datum (the mountain), many Coordinate Reference Systems (CRS)
- Two linear functions *versus* one quadratic function
- **CRS 1 & 2 con:** Cannot easily perform cross-CRS computations
- **CRS 3 con:** Non-linear functions are hard (*e.g. elliptic integrals*)

# Minkowski Coordinate System (CS)

Addition to ISO 19111 types: CartesianCS, AffineCS, EllipsoidalCS, SphericalCS, CylindricalCS, etc.

- 4-dimensional  $(x, y, z, t)$  with time multiplied by  $c$
- Non-euclidean distance  $\Delta s^2 = \Delta x^2 + \Delta y^2 + \Delta z^2 - \Delta t^2$
- Valid in context of special relativity (inertial, no gravity)
- Good approximation on short distances in general relativity (see previous slide: trade-off between extent and complexity)
- Needed for objects moving at high speed

# Inertial Reference Frame



- `InertialCRS` very similar to `GeodeticCRS`
- Axes at fixed position relative to stars
- Contains `CelestialBody` element

# Test on Dimorphos

```
<gsp:InertialCRS xmlns:gml = "http://www.opengis.net/gml/3.2"
                 xmlns:gsp = "http://www.opengis.net/gsp/1.0">
  ...snip...
  <gml:name codeSpace="JPL:HORIZONS">Dimorphos satellite (inertial)</gml:name>
  <gml:scope>For use with the reconstructed trajectory of the Didymos system.</gml:scope>
  <gml:cartesianCS>...snip...</gml:cartesianCS>
  <gsp:inertialReferenceFrame>
    <gsp:InertialReferenceFrame gml:id="DimorphosDatum">
      ...snip...
      <gsp:celestialBody>
        <gsp:CelestialBody gml:id="Dimorphos">
          <gml:identifier codeSpace="JPL:HORIZONS">urn:ogc:def:body:JPL::120065803</gml:identifier>
          <gml:name>Dimorphos</gml:name>
        </gsp:CelestialBody>
      </gsp:celestialBody>
      <gml:ellipsoid>
        <gsp:TriaxialEllipsoid gml:id="DimorphosEllipsoid">
          ...snip...
          <gsp:semiMedianAxis uom="urn:ogc:def:uom:EPSG::9001">87</gsp:semiMedianAxis>
        </gsp:TriaxialEllipsoid>
      </gml:ellipsoid>
    </gsp:InertialReferenceFrame>
  </gsp:inertialReferenceFrame>
</gsp:InertialCRS>
```

# Using trajectory data

- Transformation **between a pair of CRS** in a separated file  
(late-binding approach: **no universal hub**)
- Trajectory of one CRS relative to the other  
(can be stored as an OGC Moving Feature)
- File to use chosen by the referencing library

# OGC Moving Features JSON

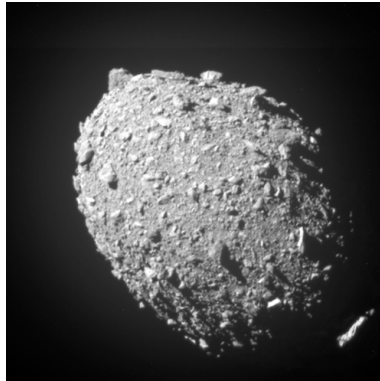
- JSON encoding extension for OGC Moving Features, GeoJSON extension
- Encodes changing geometry over time
- Supports constant properties as well as properties changing over time
- Basis for following demonstration
  - Converted data retrieved from NASA JPL Horizons System
  - Features: DART Spacecraft, LICIACube, Didymos, Dimorphos
  - Positions, velocities, TDB / UT offset...
  - Generated for different CRSs:
    - BCRS (used for demo), GCRS, Didymos/Dimorphos, Didymos

# OGC Moving Features JSON (example)

```
{
  "type": "FeatureCollection",
  "crs" : { "type" : "name", "properties" :
    { "name" : "http://www.opengis.net/def/crs/IAU/0/BCRS" } },
  "features": [
    {
      "type": "Feature",
      "id": 1,
      "geometry": {
        "type": "LineString",
        "coordinates": [
          [
            68240910.38511497,
            120050514.8471484,
            52064856.98546032
          ],
          ...
        ]
      },
      "properties": {
        "name": "DART (spacecraft)",
        "JPLHorizonsID": -135,
        "datetimes": [
          "2021-11-24T07:17:53Z",
          "2021-11-24T07:22:53Z",
          ...
        ]
      }
    }
  ]
}
```

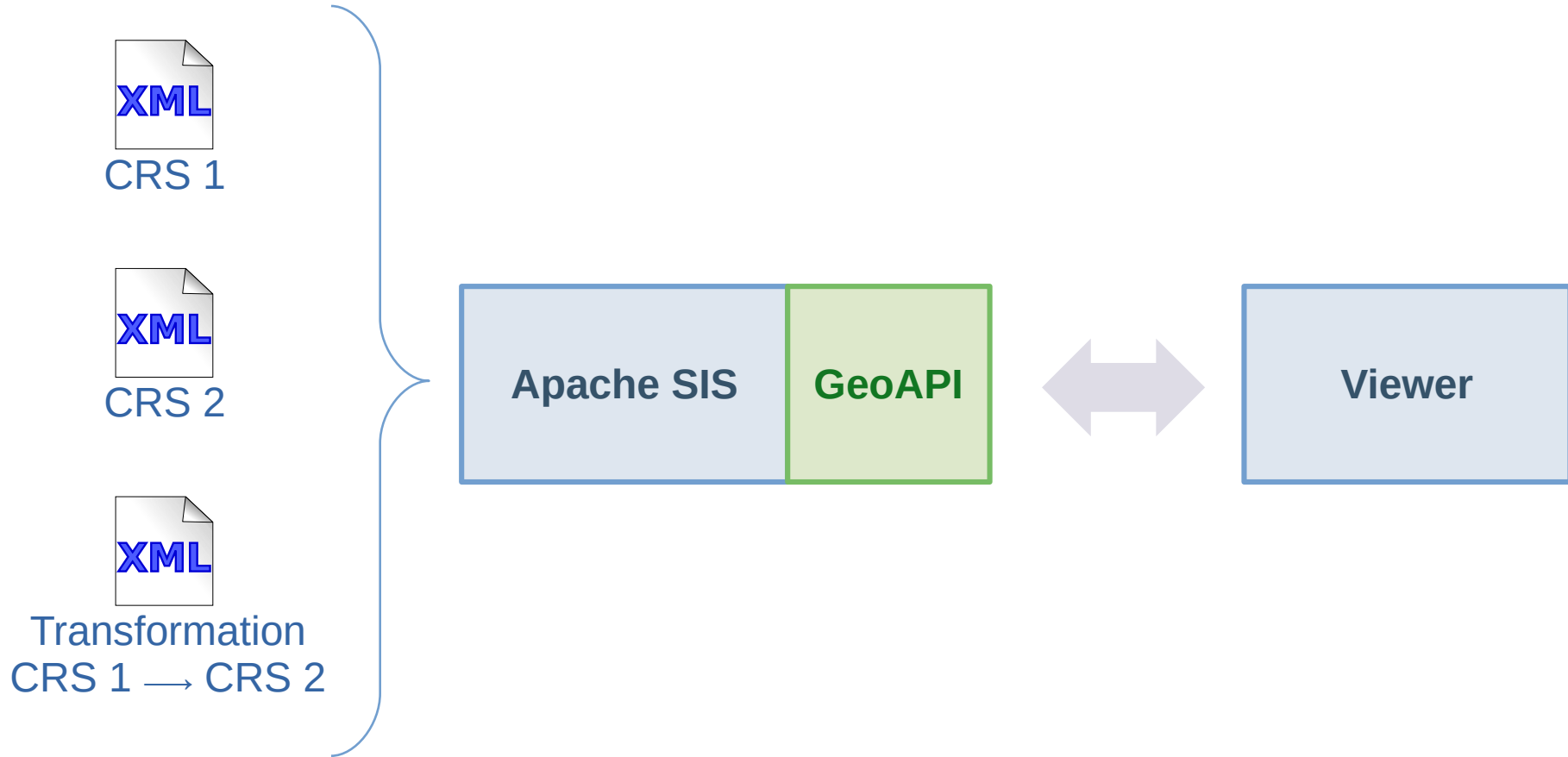
# GeoTIFF

- New geokeys for InertialLCRS & EngineeringCRS
- Coordinates of image corners can be at infinity



- Engineering Report proposes changes to GeoTIFF standard
- Reader & writer prototype on an Apache SIS branch



# Putting everything together



# Visualization Experiments

- Using Naval Observatory Vector Astrometry Subroutines (NOVAS)
  - for coordinate reference system conversions (inertial / Earth-fixed)
  - for solar system simulation (planet positions)
- Based on GNOSIS library and Ecere 3D engine
- 3D Models from NASA, John Hopkins Applied Physics Laboratory (APL)
- Gaia Sky in Colour from European Space Agency
- Still work in progress

# GNOSIS Geospatial Software

- **Ecere Corporation** (<https://ecere.ca>) 
  - OGC member since 2016 contributing in innovation and standard activities
- Free & Open Source Cross-Platform **Ecere SDK** (<https://ecere.org>)
  - GUI Toolkit, 2D/3D Graphics, VR/AR, Desktop / Mobile / Web, IDE, bindings generator for C / C++ / Python (*since 1996*)
- **eC Programming language** (<https://ec-lang.org>)
  - Compiled / Native object-oriented superset of C, properties, reflection, dynamic modules (*since 2004*)
- **GNOSIS Geospatial Software** (<https://ecere.ca/gnosis>) 
  - GNOSIS Map Server, GNOSIS Cartographer, GNOSIS SDK (*since 2014*)

# International Space Station

2023-01-18T12:13:53Z

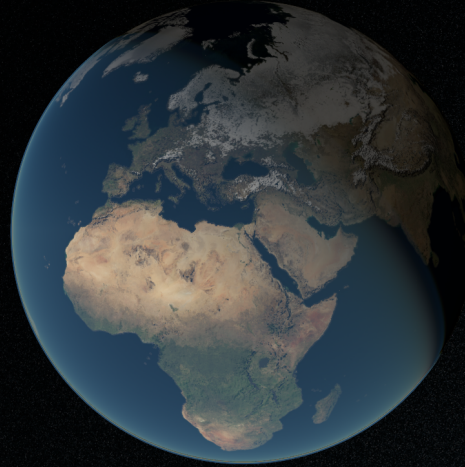
**Earth-Centered Earth-Fixed** Camera  
**GeoPose**  
lat: -48.05654361743 ° lon: -68.0501916195669 ° h: 430727.2071496346737 m  
w: 0.0557097493969 r: 0.359492464127 y: -0.5191747032992 z: -0.303991397662  
yaw: -82.0052157177989 pitch: 56.2046731949076 roll: -0.000032203165  
**ITRS**  
x: 0.0000113140479 au, y: -0.0000280739476 au, z: -0.0000338845789 au  
**Earth-Centered Inertial**  
**GCRS (equatorial)**  
x: -0.0000183843573 au, y: -0.0000241033702 au, z: -0.0000338431951 au  
dec (b): -48.148299370716 ° ra (a): 232.6661567400745 ° r: 0.0000454347764 au  
**Ecliptic (geocentric)**  
lat (l): -68.168217637804 ° lon (g): 242.672050520397 ° Δ: 0.0000454347764 au  
x: -0.0000183843583 au, y: -0.0000355764567 au, z: -0.000024627586 au  
**Heliocentric**  
**BCRS (equatorial)**  
x: -0.4880338822553 au, y: 0.7982905701702 au, z: 0.3462628890017 au  
dec (b): 20.5151233685512 ° ra (a): 120.3828845280945 ° r: 0.9889392010296 au  
**Ecliptic (heliocentric, mean ecliptic / J2000.0 equinox)**  
lat (l): 0.0038075317953 ° lon (g): 118.2747189076105 ° r: 0.9889392010296 au  
x: -0.4880333498951 au, y: 0.80175224989 au, z: 0.0031494322626 au

**Earth-Centered Earth-Fixed** ISS  
**GeoPose**  
lat: 48.4049534988641 ° lon: -68.0571022381577 ° h: 429896.2000012397766 m  
w: -0.2173884380404 r: -0.1 y: 0.5762651740532 z: 0  
yaw: 154.898620946972 pitch: 0 roll: 0  
**ITRS**  
x: 0.0000113093988 au, y: -0.0000280722622 au, z: -0.0000338800812 au  
**Earth-Centered Inertial**  
**GCRS (equatorial)**  
x: -0.0000183828262 au, y: -0.0000240996142 au, z: -0.0000338386854 au  
dec (b): -48.147612835125 ° ra (a): 232.6591894381864 ° r: 0.0000454292231 au  
**Ecliptic (geocentric)**  
lat (l): -28.1899080808881 ° lon (g): 242.667763061022 ° Δ: 0.0000454292231 au  
x: -0.00001838282935 au, y: -0.0000355702115 au, z: -0.0000246698618 au  
**Heliocentric**  
**BCRS (equatorial)**  
x: -0.488033831755 au, y: 0.7982905750261 au, z: 0.3462628935014 au  
dec (b): 20.5151233685512 ° ra (a): 120.3828845280945 ° r: 0.9889392010296 au  
**Ecliptic (heliocentric, mean ecliptic / J2000.0 equinox)**  
lat (l): 0.0038076249159 ° lon (g): 118.274718908102 ° r: 0.9889392010296 au  
x: -0.4880338317653 au, y: 0.801527364652 au, z: 0.0031484351929 au

# Earth

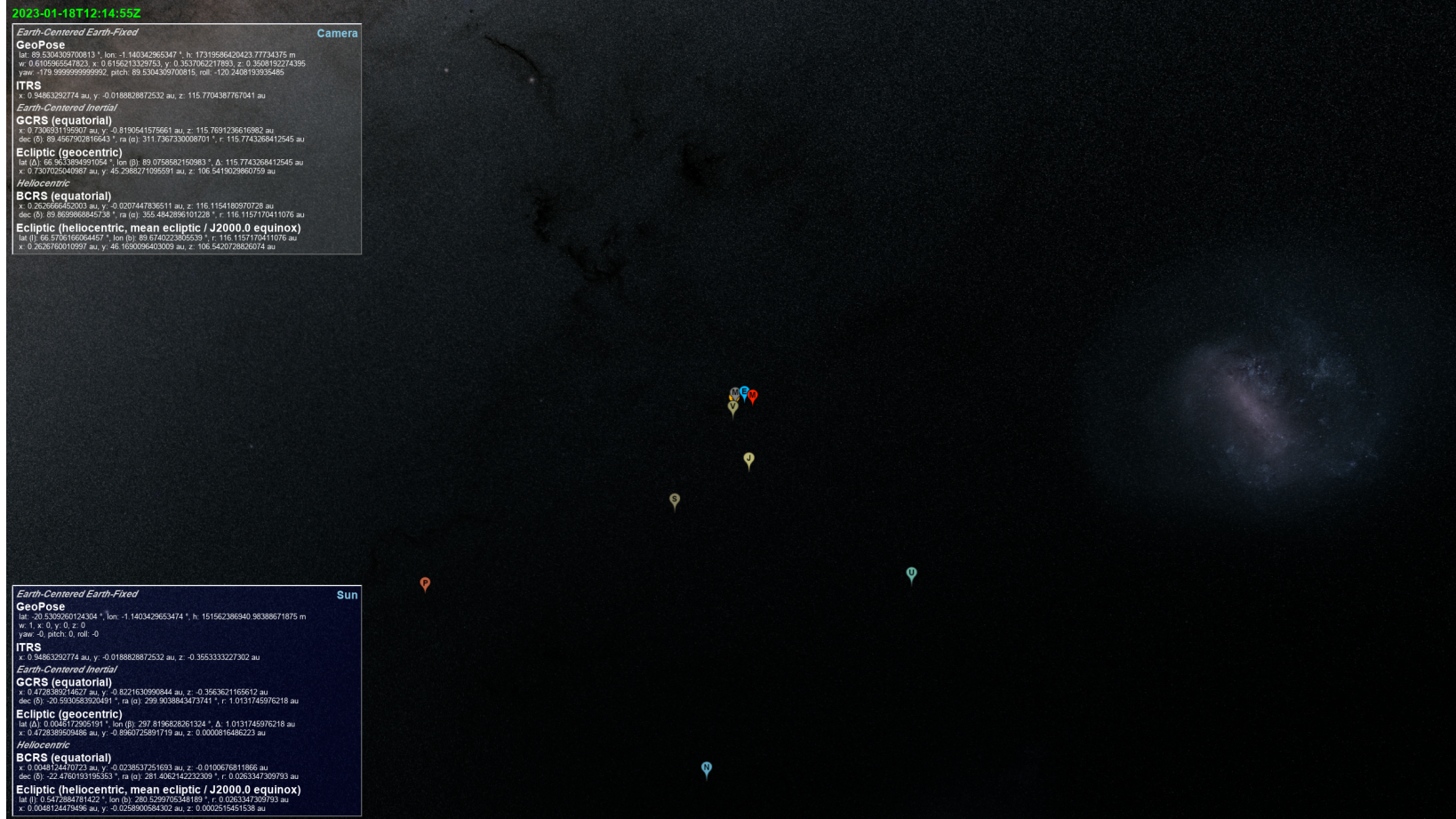
2023-02-01T13:20:05Z

**Earth-Centered Earth-Fixed** Camera  
**GeoPose**  
lat (°): 23.97883378179 °, lon: 32.0935414036712 °, h: 38959798.765752668841 m  
w: -0.70568903591, x: -0.70568903591, y: -0.0447547159122, z: -0.0447547159122  
yaw: 1.2576633468639, pitch: 90, roll: 0  
**ITRS**  
x: 0.000222993825 au, y: 0.0001398487732 au, z: 0.0001501446515 au  
**Earth-Centered Inertial**  
**GCRS (equatorial)**  
x: 0.0002631116633 au, y: 0.0000152240378 au, z: 0.0001495690228 au  
dec (°): 23.97883378179 °, ra (°): 3.1115291825462 °, r: 0.0003030303077 au  
**Ecliptic (geocentric)**  
lat (Δ): 25.6475712389997 °, lon (β): 15.5993654971609 ° Δ: 0.0003030303077 au  
x: 0.0002631116743 au, y: 0.0000734899306 au, z: 0.0001311619319 au  
**Heliocentric**  
**BCRS (equatorial)**  
x: -0.689220988657 au, y: 0.6706232220245 au, z: 0.2910846681612 au  
dec (°): 17.0791083689637 °, ra (°): 134.9400836909093 °, r: 0.9911225682705 au  
**Ecliptic (heliocentric, mean ecliptic / J2000.0 equinox)**  
lat (Δ): 0.0117194204397 °, lon (β): 132.4709624092612 ° Δ: 0.9911225682705 au  
x: -0.6892221198841 au, y: 0.7310715462061 au, z: 0.000306464874 au



**Earth-Centered Earth-Fixed** Earth  
**GeoPose**  
lat (°): 0 °, lon (°): 0 °, h: -6378137 m  
w: 1, x: 0, y: 0, z: 0  
yaw: 0, pitch: 0, roll: 0  
**ITRS**  
x: 0 au, y: -0 au, z: 8.085186120285254e-23 au  
**Earth-Centered Inertial**  
**GCRS (equatorial)**  
x: 1.7996914594342e-25 au, y: 2.284379502200854e-27 au, z: 8.085160193891029e-23 au  
dec (°): 89.8726720000000 °, ra (°): 0.7392277639496 °, r: 8.085186120285254e-23 au  
**Ecliptic (geocentric)**  
lat (Δ): 66.5287654563302 °, lon (β): 89.6794442523204 ° Δ: 8.085186120285254e-23 au  
x: 1.799691279536343e-25 au, y: 3.216303614210321e-23 au, z: 7.417904141654922e-23 au  
**Heliocentric**  
**BCRS (equatorial)**  
x: -0.689485207429 au, y: 0.6706079979867 au, z: 0.2909350091384 au  
dec (°): 17.0676723661342 °, ra (°): 134.9519560217494 °, r: 0.9912469388918 au  
**Ecliptic (heliocentric, mean ecliptic / J2000.0 equinox)**  
lat (Δ): 0.0161326210925 °, lon (β): 132.4620767077166 ° Δ: 0.9912469388918 au  
x: -0.689485214584 au, y: 0.7309980872755 au, z: 0.0001753029421 au

# Solar System



# Didymos & Dimorphos

2022-07-18T09:22:53Z

**Earth-Centered Earth-Fixed** Camera

**GeoPose**  
lat: -19.0103439923557 °, lon: -99.3384834896864 °, h: 62461448943.516487121582 m  
w: -0.4570727858884, x: 0.8601964414144, y: -0.0585828437083, z: 0.2184367208169  
yaw: -146.4936379561886, pitch: -54.285719253484, roll: -170.2459402235108

**ITRS**  
x: -0.0640624070025 au, y: -0.3895649325492 au, z: -0.1360192152709 au

**Earth-Centered Inertial**

**GCRS (equatorial)**  
x: 0.3638319477569 au, y: -0.1525674054943 au, z: -0.1368048104348 au  
dec (δ): -19.1243822720744 °, ra (α): 337.2499989542484 °, r: 0.4175716173137 au

**Ecliptic (geocentric)**  
lat (Δ): -8.9313248561392 °, lon (β): 331.884378776086 °, Δ: 0.4175716173137 au  
x: 0.36383194775349 au, y: -0.194395663184 au, z: -0.0648282012258 au

**Heliocentric**

**BCRS (equatorial)**  
x: 0.791493060447 au, y: -0.9931443066848 au, z: -0.5009739296366 au  
dec (δ): -21.528256195131 °, ra (α): 308.5533300071746 °, r: 1.3652002625299 au

**Ecliptic (heliocentric, mean ecliptic / J2000.0 equinox)**  
lat (l): -2.7115546125338 °, lon (b): 305.479611313006 °, r: 1.3652002625299 au  
x: 0.7914930903853 au, y: -1.1104680343034 au, z: -0.0645847464531 au

**Earth-Centered Earth-Fixed** Didymos

**GeoPose**  
lat: -19.0103461579751 °, lon: -99.3384850061308 °, h: 62461452882.1158752441406 m  
w: -0.7703991034492, x: -0.0807831596003, y: -0.5456725396425, z: 0.31968885703458  
yaw: 66.3169492166485, pitch: -12.9687744712583, roll: -36.5795844730001

**ITRS**  
x: -0.064062420518 au, y: -0.3895649503428 au, z: -0.1360192387691 au

**Earth-Centered Inertial**

**GCRS (equatorial)**  
x: 0.3638319618845 au, y: -0.1525674227646 au, z: -0.1368048339633 au  
dec (δ): -19.1243844363894 °, ra (α): 337.2499974346776 °, r: 0.4175716436416 au

**Ecliptic (geocentric)**  
lat (Δ): -8.9313260325811 °, lon (β): 331.8843766146501 °, Δ: 0.4175716436416 au  
x: 0.3638319616625 au, y: -0.1943956883884 au, z: -0.064828215943 au

**Heliocentric**

**BCRS (equatorial)**  
x: 0.7914930745746 au, y: -0.9931443239551 au, z: -0.5009739531651 au  
dec (δ): -21.5282567700997 °, ra (α): 308.5533300020014 °, r: 1.3652002919183 au

**Ecliptic (heliocentric, mean ecliptic / J2000.0 equinox)**  
lat (l): -2.7115551724769 °, lon (b): 305.4796111817277 °, r: 1.3652002919183 au  
x: 0.7914931045129 au, y: -1.110468095077 au, z: -0.0645847611703 au

# Double Asteroid Redirection Test (DART)

2022-09-26T23:17:44Z

**Earth-Centered Earth-Fixed** Camera

**GeoPose**  
lat: -33.351044725442 °, lon: 55.8971476825793 °, h: 11314532080.8883113861084 m  
w: 0.5145172160328, x: -0.2977680339855, y: -0.7629508997568, z: -0.253992434735  
yaw: -110.0384063807672, pitch: 4.6548980910423, roll: -45.8978626920051

**ITRS**  
x: 0.035442406774 au, y: 0.0523426029867 au, z: -0.0416038367361 au

**Earth-Centered Inertial**

**GCRS (equatorial)**  
x: 0.0398792065616 au, y: 0.0489711783394 au, z: -0.0416924944394 au  
dec (β): -33.4313409092171 °, ra (α): 50.842683581167 °, r: 0.0756755675004 au

**Ecliptic (geocentric)**  
lat (Δ): -49.7191690869121 °, lon (β): 35.4049588029141 °, Δ: 0.0756755675004 au  
x: 0.0398791997365 au, y: 0.0283458669817 au, z: -0.0577317310493 au

**Heliocentric**

**BCRS (equatorial)**  
x: 1.0314165901342 au, y: 0.1065403061947 au, z: -0.0165219510698 au  
dec (β): -0.9128688491912 °, ra (α): 5.8974589722838 °, r: 1.0370361673896 au

**Ecliptic (heliocentric, mean ecliptic / J2000.0 equinox)**  
lat (l): -3.1805808404411 °, lon (b): 5.0517919584519 °, r: 1.0370361673896 au  
x: 1.0314165901619 au, y: 0.0911768088617 au, z: -0.0575379634429 au

**Earth-Centered Earth-Fixed** Dart

**GeoPose**  
lat: -33.3510447697905 °, lon: 55.8971475370148 °, h: 11314532078.8060722351074 m  
w: -0.7686968564632, x: -0.1719161376885, y: -0.607539033124, z: 0.1022071802647  
yaw: 78.1879660226791, pitch: 8.0543901131999, roll: -21.6953173092424

**ITRS**  
x: 0.0354424068824 au, y: 0.0523426028603 au, z: -0.0416038367773 au

**Earth-Centered Inertial**

**GCRS (equatorial)**  
x: 0.0398792066582 au, y: 0.0489711782039 au, z: -0.0416924944809 au  
dec (β): -33.4313409538095 °, ra (α): 50.8426834355748 °, r: 0.0756755674865 au

**Ecliptic (geocentric)**  
lat (Δ): -49.7191690807979 °, lon (β): 35.4049586029504 °, Δ: 0.0756755674865 au  
x: 0.0398791998331 au, y: 0.0283458668409 au, z: -0.0577317310334 au

**Heliocentric**

**BCRS (equatorial)**  
x: 1.0314165991308 au, y: 0.1065403060592 au, z: -0.0165219511012 au  
dec (β): -0.9128689514106 °, ra (α): 5.8974589642974 °, r: 1.0370361674724 au

**Ecliptic (heliocentric, mean ecliptic / J2000.0 equinox)**  
lat (l): -3.1805808393103 °, lon (b): 5.0517919502189 °, r: 1.0370361674724 au  
x: 1.0314165902585 au, y: 0.0911768087209 au, z: -0.0575379834271 au

